Algal Diversity and Bio-indication of Water Resources in Israel

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Abstract

Israel Rivers are small and mostly located in the coastal plane and in the northern mountainous part as well as following across the Lake Kinneret to the Dead Sea area. The Zin Stream is the only permanent flow in the Negev Desert. The algae of Israel Rivers have been only episodically studied till 2001. The Israel Ministry of Environment survey system does not include biological parameters in the monitoring of the rivers at all. Our study of the riverine ecosystems in 2001-2011 has revealed 671 species belonging to 9 divisions. Most species are bio-indicators for salinity, acidity, temperature, streaming, oxygenation, and organic pollution. In order to implement the EU Water Framework Directive we used the algal diversity and the environmental variables of their habitats for construction of the biological part of the Israel monitoring system. According to the bio-indication analysis, the majority of the rivers are carbonate, natural clean in the upper reaches but moderately polluted under anthropogenic impact in the lower reaches. The calculated indices of water quality include the River Pollution Index (RPI), assessing the disturbance of riverine ecosystems as a result of anthropogenic impact and seasonal climate fluctuations. The saprobity indices show a low to moderate organic pollution of large fluctuation amplitude during dry and wet seasons. The new indices of ecosystem toxicity are the Water Ecosystem State Index (WESI), revealing the impact of photosynthesis and correlation of organic pollution with toxicity, in particular in the Upper Jordan River, Yarqon, Qishon and Hadera rivers. This index can be used for rapid integral assessment of ecosystem sustainability. Ecological mapping was performed for assessing seasonality of pollution: while the Upper Jordan River Basin was heavy polluted in winter, the coastal rivers Qishon, Hadera, Alexander and Yarqon are more polluted during summer. This study shows that algal diversity can be used as a tool in the biological monitoring of water resources in Israel.

Keywords

Algal Diversity; Rivers; Bio-Indication; Diversity Indices; Ecological Mapping; Israel

Introduction

Many serious health problems, especially important for the arid and semi-arid areas such as Israel, are caused by the toxic substances released into surface waters and penetrating drinking water. The only solution for this major problem is a reinforcement of the regulation system identifying the sources of pollution and prohibiting further contamination, as well as increasing resilience of aquatic ecosystems and performing the self-purification process [1].

Bio-monitoring, the environmental risk assessment using indicator organisms, has become a widely known and accepted method for water quality assessment in the European Union [2-6], which has issued a set of water quality assessment guidelines [7]. These define the biological assessment of surface water quality to be an integral part of the entire aquatic assessment concept [8].

The bio-monitoring assessment relies on the indicator species and aquatic communities variations in response to environmental changes, in particular those caused by polluting agents they are subjected to. Species that have a predicted response to changes in a selected variable can serve as bio-indicators, reflecting the reactions of aquatic ecosystems to eutrophication, pH levels (acidification), salinity, and organic pollution [9-11].

Ultimately, these assessments provide objective information necessary to enable decision-makers to choose an optimal strategy in the matters concerning the protection and sustainable use of environmental resources.

The Israel Rivers are small and located mostly in the coastal plane and in the northern part of the country. The largest is the Jordan River flowing from the Mount Hermon piedmonts through the Lake Kinneret and to the Dead Sea area (**Figure 1**). The Zin Stream is the only permanent flow in the Negev Desert.

The algae of the Israel Rivers have been only

episodically studied till 2001. The biodiversity of freshwater algae was only sporadically studied till 2000, but a considerable diversity has been revealed, including about 1200 species, many of which can be used as bioindicators [13]. However, The Ministry of Environment of Israel survey system has not included biological parameters in the river monitoring at all.

In this study we summarize our research of the riverine algal communities in Israel rivers in order to reveal the major parameters of diversity and environment that can be used for developing the biological part of the river monitoring system in the country.

FIGURE 1 MAP OF RIVERS IN ISRAEL (BASE ON [12])

Material and Methods

Sampling procedure

In the absence of biological monitoring stations, we sampled benthic or periphytic algal communities at the chemical monitoring points in the first place. If the results were not enough for evaluating the ecological status of the river, we added few stations for biological assessment of water quality and sustainability of aquatic communities.

The periphyton samples were collected by scratching boulders and submersed plants. The material was placed in 15 ml plastic tubes, and preserved in 3% neutral formaldehyde [14]. The algae and cyanobacteria were studied with the SWIFT and OLYMPUS dissecting microscopes under magnifications 740x–1850x from three repetitions of each sample and were photographed with a DC (Inspector 1). The diatoms were prepared by the peroxide technique [15] modified for glass slides [16] and were fixed in Canada balsam from two repetitions of each sample. Water temperature, acidity (pH), conductivity (Ec) and TDS were measured for each station with HANNA HI 9813-3. This meter has a full-spectrum pH measurement range. The Ec range extends to 4.00 mS cm^{-1}. The TDS fluctuates from 0 to 1999 mg l^{-1}. The measurements were made by submerging the probe into water till the reading was stabilized. The concentration of N-NO_3 was measured with HANNA HI 93728.

More environmental variables such as dissolved oxygen, nitrates (N-NO_3), total nitrogen (TN), total dissolved solids (TDS), biological organic demand (BOD), total phosphorus (P), and ammonia (N-NH_4) were measured by the Yarqon Authority at the BACTOCHEM laboratories (BACTOCHEM Ltd. Weizman Science Park, Ness-Ziona, Israel), and Newe Yar Chemical Laboratory using the high precision quantification standards.

Diversity and ecology of species

The taxonomy of this study mainly follows the systems adopted in the "Süswasserflora von Mitteleuropa" [17-23], on green algae by [24], with additions for individual taxa [25-37]. The taxonomy follows the modern taxonomical system [38], which includes the recent taxonomic revision.

On the basis of the revealed species diversity we used the taxonomical criteria as well as the numerical included species density characteristics. The density was assessed using the 6-score scale [39] (**Table 1**) modified for cell numbers by [40] and summarized in [41].

TABLE 1 SPECIES FREQUENCIES ACCORDING TO THE 6-SCORE SCALE

Score	Visual Estimate	Cell numbers per litre	Cell numbers per slide
1	Occasional	1- 10^3 cells l^{-1}	1-5 cells per slide
2	Rare	10^3-10^4 cells l^{-1}	10-15 cells per slide
3	Common	10^4- 10^5 cells l^{-1}	25-30 cells per slide
4	Frequent	10^5- 10^6 cells l^{-1}	1 cell over a slide transect
5	Very frequent	10^6- 10^7 cells l^{-1}	Several cells over a slide transect
6	Abundant	More than 10^7 cells l^{-1}	One or more cells in each field of view

Indices calculation

We compared several indices of organic pollution, such as S [42], DAIpo [43] and EPI-D [44] and choose the index S as the most informative for the river communities in Israel that contain many greens and cyanobacteria that are not included in the other (diatom) indices. The index S calculations were used for developing an ecosystem model by [42] that combined the jointly studied biological, chemical and physical variables r. The saprobity indices were obtained for each algal community [45-46] and then used for integral assessment of the species habitats.

The indices of saprobity are calculated as a function of the indicator species numbers and their relative abundances:

$$S = \sum sh / \sum h \qquad (1)$$

where S – Index of saprobity for algal community; s – species-specific saprobity level; h – abundance in the 6-scores scale [39, 41].

Ecological characteristics of the indicator species are summed up in the database [47].

The algae in the studied samples were grouped according to three major parameters: pH [48], salinity [49], and saprobity [42].

The relationship between the saprobity index and the classes of water quality identified on the basis of [50] and [42] scales are presented in **Table 2**.

TABLE 2 ECOLOGICAL WATER QUALITY CLASSIFICATION [41,47]

Water quality Class	Rank	N-NH_4 mg l^{-1}	N-NO_2 mg l^{-1}	N-NO_3 mg l^{-1}	P-PO_4^{3-} mg l^{-1}	O_2 %	Conductivity μsm cm^{-1}	Saprobity Index S
I - high	1	< 0.05	0	< 0.05	< 0.005	100	< 400	< 0.5
II - good	2	0.05-0.10	0.001-0.002	0.05-0.20	0.005-0.015	91-100	400-700	0.5-1.0
II - good	3	0.11-0.20	0.003-0.005	0.21-0.50	0.016-0.030	81-90	400-700	1.0-1.5
III - moderate	4	0.21-0.30	0.006-0.010	0.51-1.00	0.031-0.050	71-80	700-1100	1.5-2.0
III - moderate	5	0.31-0.50	0.011-0.020	1.01-1.50	0.051-0.100	61-70	700-1100	2.0-2.5
IV - poor	6	0.51-1.00	0.021-0.050	1.51-2.00	0.101-0.200	51-60	1100-1300	2.5-3.0
IV - poor	7	1.01-2.50	0.051-0.100	2.01-2.50	0.201-0.300	31-50	1100-1300	3.0-3.5
V - bad	8	2.51-5.00	0.101-0.300	2.51-4.00	0.301-0.600	10-30	1300-1600	3.5-4.0
V - bad	9	> 5.00	> 0.300	> 4.00	> 0.600	> 10	> 1600	> 4.0

The integral index of river pollution (RPI) was calculated for the critical chemical variables measured over the sampling stations of a river on the basis of the integral method of [51] and [43]. The integral index of river pollution (RPI, [51]) is based on the pollution estimates (such as the saprobity indices) for each of the sampling stations. The integral indices are calculated as:

$$RPId = \sum (D_i + D_j) \times l / 2L \qquad (2)$$

where *Di*, *Dj* – the saprobity indices for adjacent stations *i*, *j*;

l – Distance between two adjacent stations (km);

L – Total river length.

RPI is fairly conservative for stable ecosystems and can be used as a reference estimate of the river's ecosystem stability [51].

The integral index of aquatic ecosystem sustainability (WESI) was constructed on the basis of our studies [41, 47]. It is based on the water quality ranges (**Table 2**) as determined by the Sládeček's saprobity indices and nitrate concentrations. WESI thus reflects self-purification capacities of the river system [41, 47],

and is calculated as:

$$WESI = RankS / RankNNO3 \qquad (3)$$

where:

Rank S – the rank of water quality according to the range of the Sládeček's saprobity indices (**Table 2**) calculated for the sampling station;

Rank N-NO₃ – water quality rank according to the range of the nitric-nitrogen concentration scale (**Table 2**).

At WESI≥ 1, the p hotosynthetic level is positively correlated with the level of nitrate concentration. At WESI < 1, photosynthesis is suppressed (presumably due to a toxic disturbance).

On the basis of the complex chemical data and saprobity indices classification we performed ecological mapping for each of the river basins under study. The ecological maps were proved instrumental for finding stations and areas that are problematic for each river in respect to their ecosystem stability and self-purification.

Results and Discussion

In the first stage of our work in 2001–2009, we studied the algal species diversity in the rivers of Israel. It is represented now by 671 species of algae and cyanobacteria (**Table 3**) belonging to 9 taxonomic divisions, the full lists for each river, with ecology of the species and composition of the algal communities being published in [41,47,52-64]. This paper focuses on holistic aspects of the previously obtained biodiversity and bio-indication assessments.

Most of the species are the bio-indicators for salinity, acidity, temperature, streaming, oxygenation, and organic pollution. Therefore, it was possible to use the integral characteristics of taxonomic algal diversity and ecological variables of their habitats for implementation of the EU Water Framework Directive [7] and construction of the biological monitoring system.

The taxonomic structure analysis

The algal diversity of riverine communities at the taxonomic division level (**Table 3**) is composed of two main groups, one dominated by the green algae and the other by the diatoms. The coastal rivers Hadera and Alexander and the Lower Jordan River are assigned to the first group with the prevalence of green algae. The Upper Jordan, Oren, Zin, Qishon and Yarqon rivers compose the second group with the prevalence of diatom algae.

TABLE 3 ORDINATION OF ALGAL AND CYANOBACTERIAL SPECIES DIVERSITY IN THE ISRAEL RIVERS OVER LATITUDE

Division \ River	Upper Jordan	Qishon	Oren	Hadera	Alexander	Yarqon	Lower Jordan	Zin
Bacillariophyta	112	117	103	49	41	127	56	34
Chlorophyta	48	44	36	45	52	71	31	5
Cyanobacteria	43	43	41	53	29	57	34	10
Euglenozoa	9	30	12	19	17	42	8	0
Charophyta	13	4	12	4	3	11	11	4
Heterokontophyta	2	5	6	1	3	4	4	1
Cryptophyta	0	1	2	2	0	0	2	0
Myzozoa	0	1	2	1	1	1	4	0
Rhodophyta	4	1	1	0	0	1	1	0
Total	231	246	215	174	146	314	151	54
Latitude	33.11	32.47	32.45	32.27	32.23	32.06	32.06	30.5

We then studied correlation of this higher order taxonomic grouping with ecological variables. As an example, we sum up the bio-indication analysis data on the histogram plot for the Upper Jordan River communities (**Figure 2**).

Ordering the indicator groups along the gradient of their indicator significance, we used a statistical definition approach for discriminating the major indicator groups in each system analysis. The standard deviation line and the polynomial trend line together cut off the dominate groups of species most representative for ecological evaluations. The majority of Israel rivers are carbonate, naturally clean in the upper reaches, while moderately polluted and under anthropogenic impact in the lower reaches. Thus, the Upper Jordan River algal communities are dominated by the diatoms, inhabiting alkaline fresh waters. The majority of species are the nitrogen-autotrophic taxa, tolerating an elevated concentration of organically bound nitrogen, indicating a eutraphentic to meso-

eutraphentic ecosystem state with two different types of communities, dominated by beta-mesosaprobous and by oligosaprobous taxa.

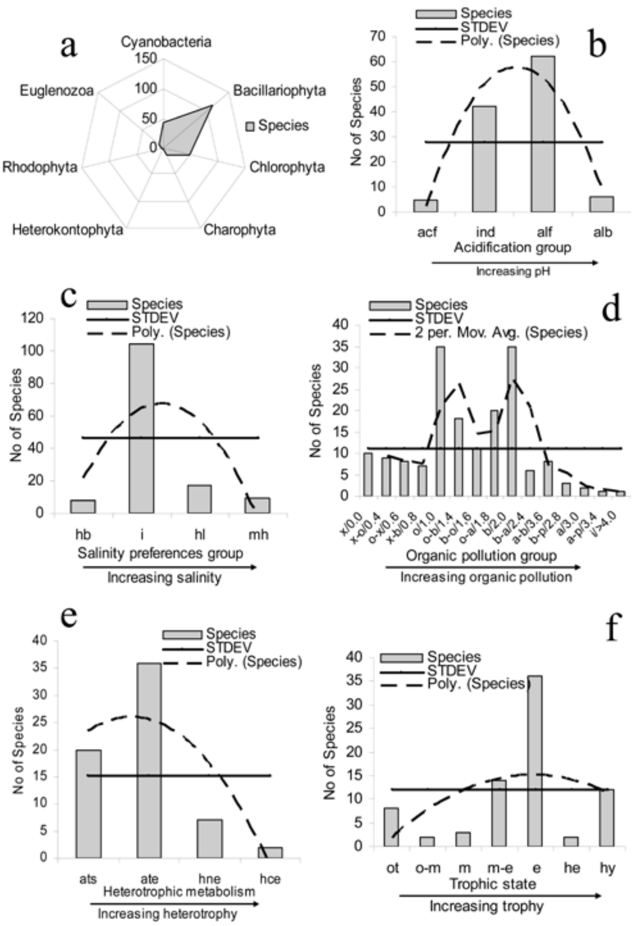

FIGURE 2 BIO-INDICATION PLOT FOR THE UPPER JORDAN RIVER COMMUNITIES

a, taxonomic composition; b, acidification groups of indicator species; c, salinity indicator groups; d, organic pollution indicators (after [42, 46]); e, nitrogen uptake metabolism and f, trophic state indicator groups (after [9]). Ecological groups: (b): Acidity–pH degree after [48] (acf–acidophilous; ind–indifferent; alf–alkaliphilous, alb–alkalibiontic); (c): Salinity–halobity degree after [49] (hb–oligohalobous-halophobous, i–oligohalobous-indifferent, hl –halophilous; mh–mesohalobous, ph–polyhalobous); (d): Saprobity S–degree of saprobity [42,45] (x–xenosaprobity, x-o–xeno-oligosaprobity, o-x–oligo-xenosaprobity, x-b–xeno-betamesosaprobity, o–oligosaprobity, o-b–oligo-betamesosaprobity, b-o–beta-oligosaprobity, o-a – oligo-alphamesosaprobity, b–betamesosaprobity, b-a–beta-alphamesosaprobity, a-b–alpha-betamesosaprobity,b-p–beta-polysaprobity, a–alphamesosaprobity, a-p–alpha-polysaprobity, p–polysaprobity, i–isosaprobity); (e): Autotrophy-Heterotrophy–nitrogen uptake metabolism [9] (ats–nitrogen- autotrophic taxa, tolerating very small concen- trations of organically bound nitrogen; ate nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen; hne–facultatively nitrogen-heterotrophic taxa, needing periodically elevated concentrations of organically bound nitrogen; hce–obligately nitrogen-heterotrophic taxa, needing continuously elevated concentrations of organically bound nitrogen); (f): Trophy–trophic state [9] (ot–oligotraphentic; o-m–oligo-mesotraphentic; m–mesotraphentic; m-e–meso-eutraphentic; e–eutraphentic; he– hypereutraphentic; hy–oligo-to eutraphentic (hypereutraphentic)).

In the next step, the integral water quality indices are calculated, such as the saprobity index S [42], which includes all species of a community, not only the diatoms. This approach is important for the rivers of Israel, because a considerable part of them is dominated by green algae (e. g. the Alexander River) and cyanobacteria (the Hadera River).

Saprobity Index S

In winter, the saprobity index S in the Upper Jordan River Basin ranged from 1.11 in the Jordan outlet with *Gomphonema parvulum* (Kützing) Kützing as a numerically dominant species to 2.08 in the Ayun River with *Cladophora glomerata* (Linnaeus) Kützing. In summer, it ranged from 0.36 in the Banias River with *Hildenbrandia rivularis* (Liebmann) J. Agardh to 2.09 in the Snir River with *Cladophora glomerata*. These S values correspond to the I-III Classes of water quality (**Table 2**), indicating a low to moderate level of water pollution. This type analysis can be used for environmental regulation, in particular because the Upper Jordan River is the major source of drinking water in Israel.

As shown in **Figures 3** and **4**, the species richness is correlated with the saprobity index S over the Upper Jordan River, as well as in the other studied rivers.

The algal community dynamics over the monitored stations in the Lower Jordan River shows the species richness fluctuations from the clean-water station 3 at the outlet from the Lake Kinneret with *Microcystis aeruginosa* (Kützing) Kützing to the polluted station 3a down the Bitania wastewater treatment plant inlet with *Oscillatoria redeckei* van Goor, then increasing over the stations 7 and 8 as a result of self-purification (**Figure 5a**). At the end of the studied part of the Lower Jordan River, the algal community is dominated by *Cladophora glomerata*. At the same time, the graphs show a correlation between the indicators of salinity on the one hand (**Figure 5a**) and organic pollution on the other (**Figure 5b**). At the stations 3a

and 5, the species richness of the algal community dramatically decreases. We can see also a decrease in the salinity-indifferent species and the proportional increase in the halotolerant meso- and polyhalobes (**Figure 5a**) together with the high class (IV-V) organic pollution indicators (**Figure 5b**).

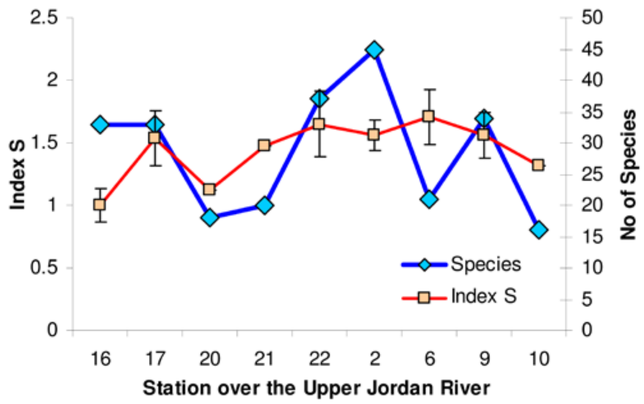

FIGURE 3 DYNAMICS OF THE ALGAL SPECIES ABUNDANCES AND THE SAPROBITY INDEX IN THE SAMPLING STATIONS OF THE UPPER JORDAN RIVER AREA, WINTER 2009.

Numbers of stations are given from the longest tributary Saar (16-22) over the Upper Jordan River monitoring stations (2-9) and down to the river mouth (10) to the Lake Kinneret.

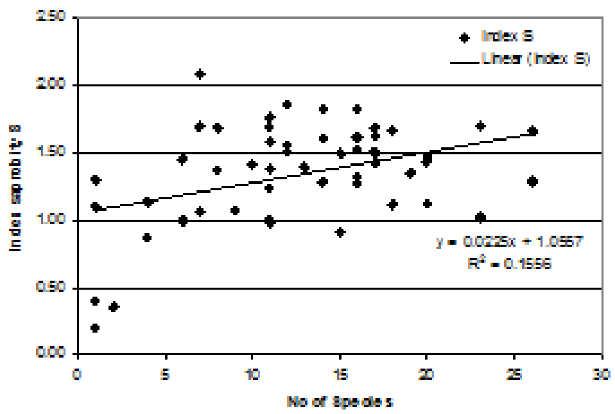

FIGURE 4 CORRELATION BETWEEN THE NUMBER OF ALGAL SPECIES AND THE SAPROBITY INDEX S IN THE SAMPLING STATIONS OF THE UPPER JORDAN RIVER AREA, WINTER 2009.

The saprobity index S calculated for the most polluted Hadera River in 2003-2009, shows moderate to high organic pollution (**Figure 6**), having the opposite signs of fluctuation during the dry and wet seasons when the upper reaches community dominant *Phormidium breve* (Kützing ex Gomont) Anagnostidis & Komárek was replaced by *Lyngbya aestuarii* (Mertens) Liebman ex Gomont at the estuary.

River Pollution Index (RPI)

The integral River Pollution Index (RPI) was calculated for each studied river, representing ecosystem sustainability. RPI shows instability of riverine communities, when they are impacted by anthropogenic pollution, as well as by seasonal climatic fluctuation. For example, RPI for the Hadera River, based on the chemical variables and saprobity indices S, shows instability during wet season (**Table 4**). In contrast, RPI of the Upper Jordan River monitoring stations remained within the ranges that reflect ecosystem stability.

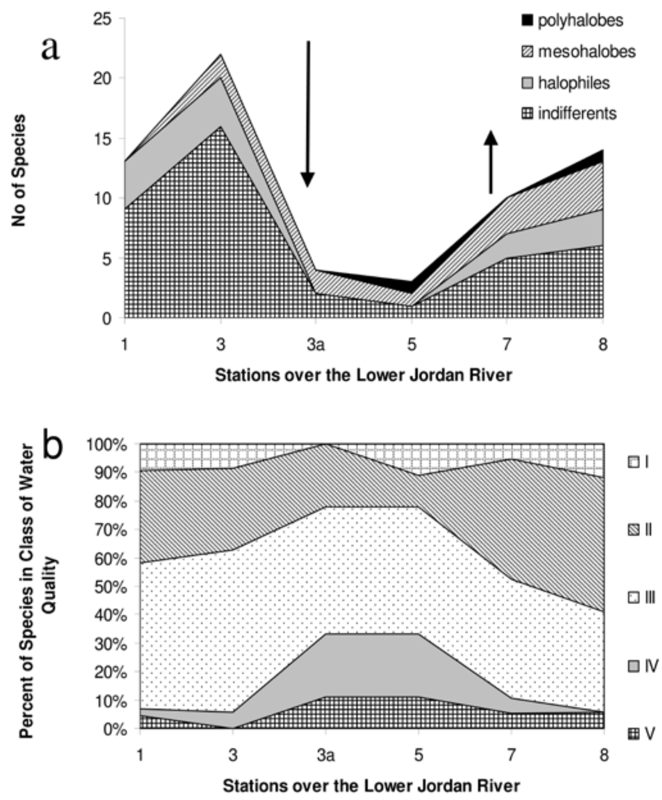

FIGURE 5 BIO-INDICATION OF THE LOWER JORDAN RIVER IN WINTER 2006:

(a) algal species richness divided to salinity indicators; (b) organic pollution indicators. Stations numbered starting from the outlet from the Lake Kinneret (1 and 3) across the Bitania wastewater treatment plant and the salinity canal inlets (3a) till the river end near the Sheih Hussein Bridge station (8) above the Dead Sea. The organic pollution groups are clustered in the water quality Classes in respect of their species-specific indices of saprobity (b). Arrows mark the impact point after Bitania and point when the rise of self-purification of ecosystem of the Lower Jordan River after it.

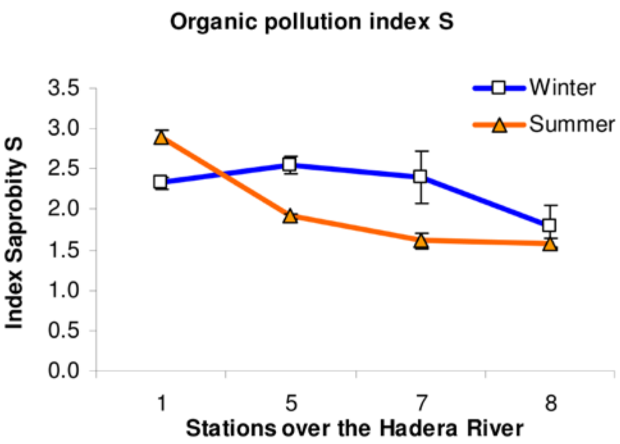

FIGURE 6 DYNAMIC OF SAPROBITY INDEX S OVER THE SAMPLING STATIONS OF THE HADERA RIVER DURING WET AND DRY SEASONS OF 2003-2009.

Water Ecosystem State Index (WESI)

New index of ecosystem toxicity, the Water Ecosystem State Index (WESI) is a criterion of the toxicity impact on photosynthesis. As can be seen in **Figure 7**, WESI for the impacted winter communities of the Upper Jordan River Basin were typically lower than one. Only the Ram Lake (Station 23) ecosystem remained sustainable, without an appreciable photosynthesis impact.

WESI can help to assess the seasonal impact on the algal communities, such as shown in **Figure 8** for the Upper Jordan River. Only the summer communities of the upper (Station 1) and lower (Station 10) retained a high photosynthesis capacity. All the winter communities were heavily impacted. Thus, the WESI confirms a stronger self-purification capability in the Upper Jordan River system during the dry season.

The WESI also shows a correlation of organic pollution with toxicity in the Upper Jordan River, as well as in the Yarqon, Qishon and Hadera rivers. The WESI's were the most informative for assessment of pollution in the Lower Jordan River. Whereas the indices of saprobity S remained within close ranges of variation in the wet and dry seasons, the WESI's were twice higher at the unpolluted stations 1 and 3 in winter (**Figure 9**). Therefore, WESI can be used for rapid integral assessment of ecosystem sustainability.

Ecological mapping of the bio-indications results

The ecological mapping approach was employed to reveal the targets and power of impacts on the freshwater riverine ecosystems. The data for the map is based on the assessments of bio-indication and chemical variables. A comparison of the density/ diversity indices and distribution of pollutants over the river basin monitoring stations, as well as a statistic approach

TABLE 4 COMPARISON OF THE RIVER POLLUTION INDEX (RPI) CALCULATED FOR THE LOW POLLUTED UPPER JORDAN RIVER AND THE HIGHLY POLLUTED HADERA RIVER OVER THE WET AND DRY SEASONS. TDS WAS MEASURED FOR LOW MINERALIZED WATER ONLY; NA – ABBREVIATED AS: CHEMICAL ANALYSIS NOT AVAILABLE

RPI	Unit	The Hadera River		The Upper Jordan River	
		Summer	Winter	Summer	Winter
RPI_{pH}	-	8.09	7.59	7.74	8.05
RPI_{T}	°C	33.09	18.72	14.71	18.56
RPI_{Ec}	sm cm^{-1}	3.480	2.630	0.436	0.388
RPI_{TDS}	mg l^{-1}	1682.45	1309	269.41	276.21
RPI_{S}	-	2.06	2.34	1.41	1.22
$RPI_{N\text{-}NO3}$	mg l^{-1}	5.76	11.07	1.76	1.36
$RPI_{P\text{-}PO4}$	mg l^{-1}	4.30	7.30	0.04	0.02
$RPI_{N\text{-}NH4}$	mg l^{-1}	19.00	23.50	0.02	0.02
RPI_{Norg}	mg l^{-1}	na	na	0.15	0.12
RPI_{Ntot}	Ntot	na	na	1.70	1.47
$RPI_{No\ Species}$	no	18.29	14.41	30.55	14.20
$RPI_{N\text{-}kjel}$	mg l^{-1}	35.20	29.40	na	na
RPI_{TSS}	mg l^{-1}	64.30	75.10	na	na
RPI_{COD}	mg O_2 l^{-1}	190.40	163.75	na	na
RPI_{NTU}	-	62.98	40.02	na	na

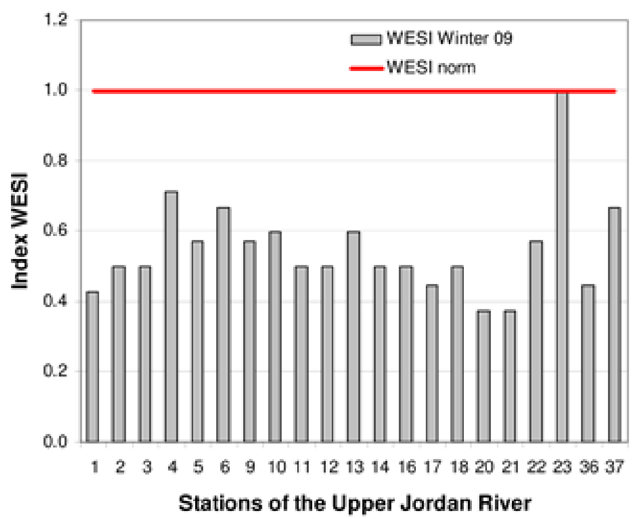

FIGURE 7 THE WATER ECOSYSTEM STATE INDICES (WESI) AT THE UPPER JORDAN RIVER STATIONS IN THE FULL SCREENING WINTER 2009

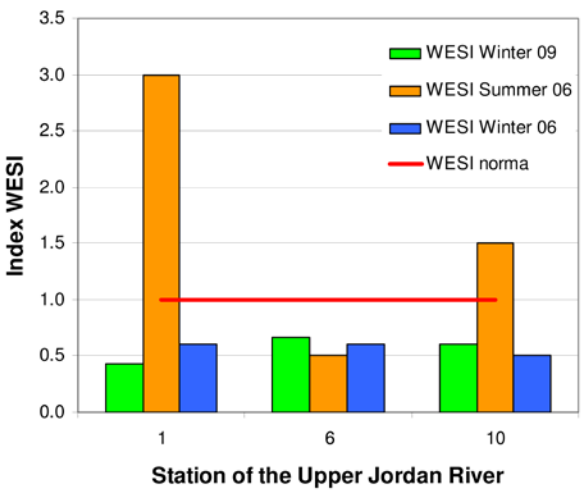

FIGURE 8 SEASONAL CHANGES OF THE WATER ECOSYSTEM STATE INDICES (WESI) AT THE UPPER JORDAN RIVER MAJOR MONITORING STATIONS IN SUMMER AND WINTER 2006 AND IN WINTER 2009

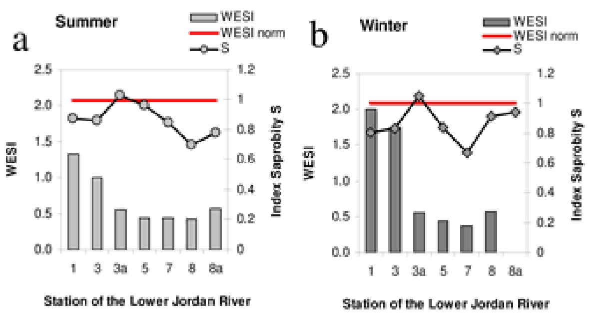

FIGURE 9 SEASONAL CHANGES OF THE WATER ECOSYSTEM STATE INDICES (WESI) AND THE SAPROBITY INDEX S AT THE LOWER JORDAN RIVER MONITORING STATIONS IN SUMMER AND WINTER 2006

and modeling were used to reveal the risk factors for the river ecosystem. Our approach to the ecological map construction included not only the mapping of the river channel water quality, as practice is in the EC country [7], but also highlighting the catchment areas that affect each of the monitoring stations. At a result of the map analysis, we distinguish not only the problematic points on the river channel, but also the objects that cause a disturbance of riverine communities. Therefore, the mapping process includes two stages: (1) construction of the nitrate concentration rank map and (2) construction of the saprobity indices rank map. Their comparison provides for location of pollution sources in the catchments area.

Ecological mapping was done, in the first time in Israel, for the Upper Jordan River Basin and later for the coastal rivers Qishon, Hadera, Alexander and Yarqon.

Ecological maps (**Figures 10, 11**) constructed for the Upper Jordan River chemical monitoring stations appear different for the wet and dry seasonal communities. Whereas the Index S map (**Figure 10a**) shows good or moderate water quality, the nitrate map (**Figure 10b**) reflects poor water quality in the Upper Jordan River in winter at most monitored stations. The summer maps show a much better situation in respect of saprobity level (**Figure 11a**) as well as nitrate concentration (**Figure 11b**). Therefore, the Upper Jordan River was mostly polluted in winter.

But the preliminary mapping analysis does not help us in locating the point sources and areas of pollution in the basin. Because of this we had to perform a detailed monitoring in the winter season of 2009 (**Figure 12**). As can be seen the self-purification capacity was high in the upper tributaries, lower reaches and the Meshushim River. But the river waters were considerably enriched in nitrates in the Saar tributary stations near Mount Hermon. The Saar can be marked out as a pollution source for the Upper Jordan River in winter. This result, obtainable with ecological mapping analysis alone, is significant for the Make Decision System, because the Upper Jordan River is a major drinking water source in Israel.

CONCLUSION

Algal diversity in the riverine communities of Israel reflects not only water quality, but also the climatic impact in the arid and semi-arid environments, bearing on the problem of future warming [41,59,65]. All Israel rivers are alkaline, which is the major characteristic which controlled the algal diversity in this carbonate province [41,66].

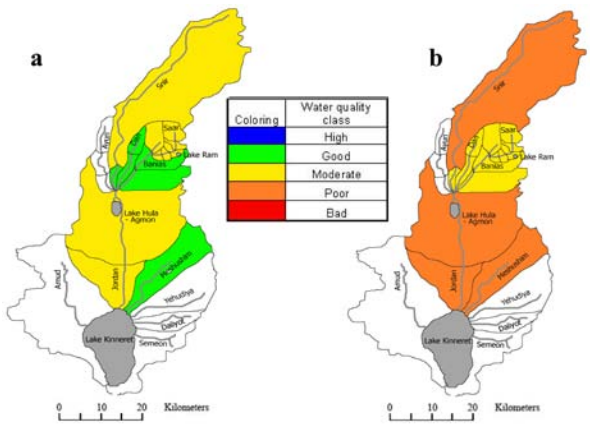

FIGURE 10 ECOLOGICAL MAPS OF THE UPPER JORDAN RIVER BASIN CONSTRUCTED ON THE BASIS OF (A) THE SAPROBITY INDEX S CLASSIFICATION RANK AND (B) THE NITRATE CONCENTRATIONS CLASSIFICATION RANK IN WINTER 2006

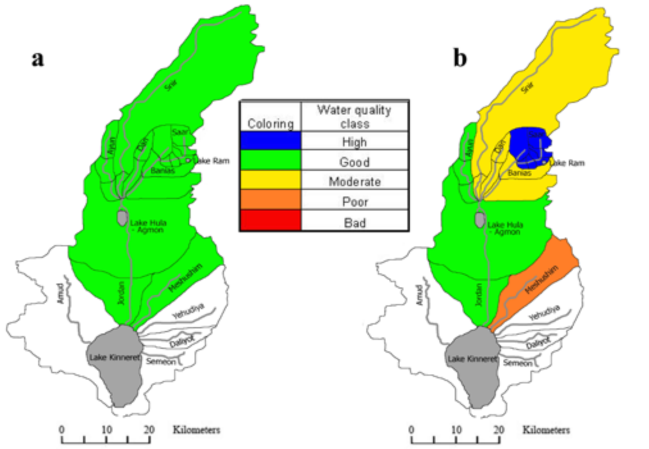

FIGURE 11 ECOLOGICAL MAPS OF THE UPPER JORDAN RIVER BASIN CONSTRUCTED ON THE BASIS OF (A) THE SAPROBITY INDEX S CLASSIFICATION RANK AND (B) NITRATE CONCENTRATIONS CLASSIFICATION RANK IN SUMMER 2006

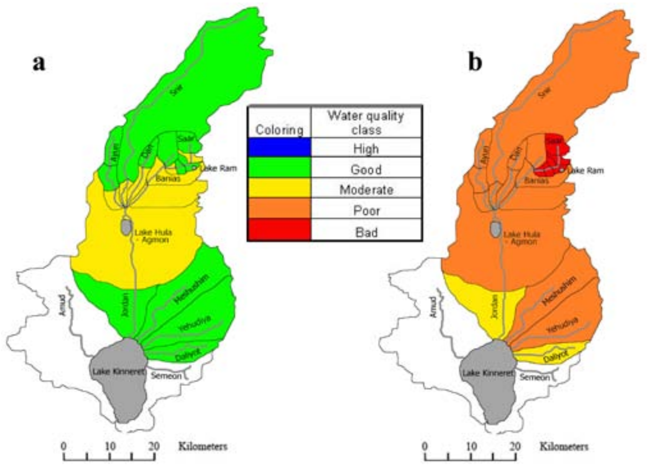

FIGURE 12 ECOLOGICAL MAPS OF THE UPPER JORDAN RIVER BASIN CONSTRUCTED ON THE BASIS OF FULL SCREENING ANALYSIS FOR (A) THE SAPROBITY INDEX S CLASSIFICATION RANK AND (B) NITRATE CONCENTRATIONS CLASSIFICATION RANK IN WINTER 2009

As the first experience of algal indication in the Israel rivers, we used a few methods for assessment of the water quality and self-purification capacity. The diversity analysis of riverine communities at the divisional differentiates between two types of algal communities, one dominated by greens or cyanobacteria and the other prevailed by the diatoms. This result is important for construction of monitoring systems adjusted to the different types of riverine communities.

The second step of the monitoring data analysis was the assembling the bio-indication plots that presented major groups of species indicators as the basis for ecological evaluation. Calculation of the saprobity indices S that are wildly used in the monitoring systems of EU countries betrays the spatial dynamics and seasonal fluctuations of pollution over the monitoring stations of each river. In particular, on account of the Saprobity Index S dynamics, we concluded that while the Upper Jordan River was mostly polluted in winter, the coastal rivers were more heavily impacted in summer. This is because the sources of anthropogenic influence on the Upper Jordan River were located in the basin catchments, whereas pollution of the coastal rivers can be related not only to anthropogenic impact on the basin catchments, but also to accumulation of pollutants in the alluvial sediments and their diffusion in summer. But in the both types of rivers the water pollution decreased toward the mouth owing to the self-purification processes.

The new index WESI, reflecting sustainability of the river ecosystem, was calculated for different types of river during different seasons. The index is based on the ecological classification of the nutrient related chemical variables, such as nitrate concentration and organic pollution indicators. The index allows us to assess the toxic impact on photosynthesis that varies over seasons owing to the different rates of nitrate uptake. The WESI informs on the self-purification capacity of aquatic ecosystems. It is concluded that photosynthesis and its self-purification correlates are most impacted in winter in the low polluted rivers (such as the Upper Jordan) and in summer in the manmade polluted rivers (such as the Lower Jordan).

The integral River Pollution Index (RPI) helps us in detecting instability of ecosystem processes and relates them to specific pollutants or their combinations (e.g. the combination of salinity and organic pollution in the Hadera River).

The ecological mapping on the basis of nutrient concentrations and algal bio-indication locates the pollution sources over the basin catchments. The maps reveal seasonality of impacts causing problems for river ecosystems. This approach gave us a detailed picture of the Upper Jordan River pollution patterns, pointing to the winter rainy season as the most problematic for this river. The Saar tributary was identified as a major pollution venue for the Upper Jordan River that flows into the Lake Kinneret, the main source of drinking water in Israel.

Thus, a complex study of algal communities, including the new regional indices, statistical approaches as well as the ecological mapping, gives important information on the river pollution and its ecosystem self-purification capacity that can be used

as a basis for the river monitoring – make decision system in Israel.

Our results can be accessible not only for the Ministry of Environment of Israel but also for other regional organizations that still formed own systems for the freshwater recourses quality monitoring and water pollution control because freshwater resources quality is one of the most important problems in this arid region in present and bearing future climate warming.

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